JOURNAL OF THE AMERICAN ROCKET SOCIETY

NUMBER 83 DECEMBER, 1950

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NUMBER 83 **DECEMBER, 1950**

ROBERTSON YOUNGQUIST, Editor

The JOURNAL OF THE AMERICAN ROCKET SOCIETY is devoted to disseminating information on the development of rocket and jet propulsion by printing original technical papers on jet propulsion, data on the latest experimental developments, historical notes, patent specifications, reviews of books and current literature, and news of the Society and individual members.

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Published Quarterly by The American Rocket Society, Inc.

Journal of The American Rocket Society, December, 1950, Volume Number 83. Published quarterly by The American Rocket Society at 20th and Northampton Streets, Easton, Pa., U. S. A. The Editorial Office is located at the Engineering Societies Building, 29 West 39th Street, New York 18, N. Y. Price, $1.00 per copy, $4.00 per year. Entered as second-class matter at the Post Office at Easton, Pa., under the Act of March 3, 1879.

JOURNAL OF THE
AMERICAN ROCKET SOCIETY

Number 83 ROBERTSON YOUNGQUIST, *Editor* December, 1950

SOME STATISTICAL CONSIDERATIONS OF THE JET ALIGNMENT OF ROCKET-POWERED VEHICLES

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JET misalignment can be defined as the perpendicular distance from the line of thrust of the rocket motor to the center of gravity of the vehicle.

Jet misalignment is of interest because the thrust of the rocket motor, acting over the misalignment distance as a lever arm, sets up a pitching (or yawing) moment about the center of gravity which tends to swing the vehicle off its prescribed trajectory. Since the thrust of a given rocket motor is established by the application in which it is to be used, the magnitude of

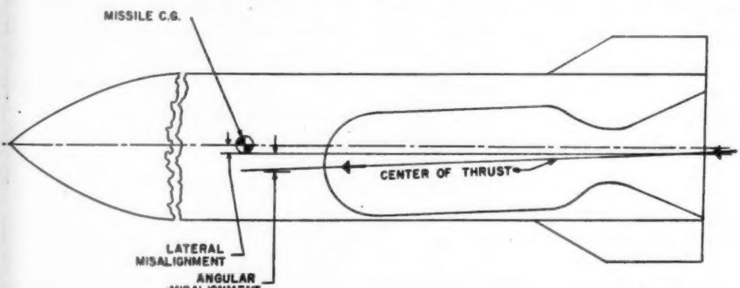

FIG. 1 LATERAL AND ANGULAR MISALIGNMENT OF ROCKET-POWERED VEHICLE

this undesirable pitching moment is determined in practice solely by the magnitude of the misalignment. This misalignment is dependent mainly upon the precision of positioning of the thrust vector and is thus a function of the thermodynamic process producing thrust and the statistical relationships involved in establishing a position by the assembly of numerous nonexact parts.

Presented before the Southern California Section of the AMERICAN ROCKET SOCIETY on June 28, 1950.

Basic Principles of Jet Misalignment

Types of Misalignment: Two types of misalignment are common. This is shown in Fig. 1 by the thrust vector which exemplifies the following two components of misalignment: (1) Lateral misalignment, when the thrust vector remains parallel to the center line of the vehicle, but is displaced laterally; and (2) angular misalignment, when the thrust vector is at an angle to the center line of the missile. In general, both types of misalignment will be present.

Location of Thrust Vector, Ideal Rocket: Before the variables which affect the position of the thrust vector can be explored, it is necessary to understand the mechanism of the rocket that produces the thrust vector. These principles are already well known. However, a brief review of the broad aspects will insure common agreement of the terminology, assumptions, and limitations of the remainder of this paper.

Postulate an ideal rocket motor as in Fig. 2 consisting of a combustion chamber and a nozzle. The combustion chamber contains an infinite reservoir of gas at a constant pressure P_c and zero velocity.

For the purposes at hand it is sufficient to note that the thermodynamics of the system result in the gas leaving the rocket system via the nozzle at a lower pressure P_e and a finite exit velocity V_e. The analysis will be simplified if it is also postulated that across any cross section of the nozzle, the gas is at uniform pressure, density, and speed. In general, the ambient atmospheric pressure P_a, will differ from P_e, the nozzle exit pressure and, for the sake of simplicity, can be postulated as bearing over the outer face of the nozzle exit section. Two distinct components of thrust can be recognized intuitively from this oversimplified idealization: (1) Thrust due to the change in momentum of the gas; and (2) thrust attributable to the difference in pressure over the exit face of the nozzle.

This intuitive approach yields the familiar equation,

$$T = \frac{W}{g}V_e + (P_e - P_a)A_e \qquad [1]$$

where

T = thrust, lb
V_e = exit velocity, fps
W = weight rate of propellant, lb per sec
A_e = nozzle exit area, sq in.
P_e = nozzle exit pressure, psia
P_a = atmospheric pressure, psia

From the foregoing approach it can be seen that the thrust due to the change in momentum, which is normally by far the major proportion of the total thrust, will be in exactly the oppo-

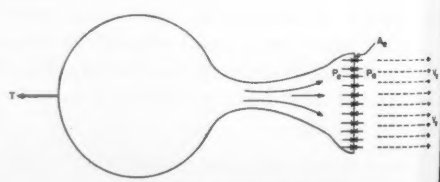

FIG. 2 IDEAL ROCKET MOTOR

site direction to the mean velocity of the exit gases—i.e., perpendicular to the plane of the nozzle exit section. Since uniform density and speed across the nozzle have been postulated, the center of thrust will be at the geometric center of the nozzle exit area—i.e., along what can be defined as the perpendicular center line of the nozzle exit section. With uniform pressure across the nozzle exit area, the thrust resulting from the pressure differential at exit will also act along the perpendicular center line of the nozzle exit area.

Accordingly, for this ideal rocket, the location and direction of center of thrust are determined by the location and direction of the nozzle exit section, and by nothing else. The tolerances of the misalignment of thrust are therefore a direct function, for the ideal rocket, of the mechanical misalignments resulting from the manufacturing tolerances of those parts which locate the nozzle exit face.

Location of Thrust Vector, Real Rocket: Of the many ways in which a real rocket differs from this ideal rocket only those that influence the orientation of the thrust vector are relevant to this paper. Two types of variables merit consideration.

The first group of variables are those (other than the exhaust gas) which produce a net nonaxial thrust on the combustion chamber. These variables consist largely of the momentum and pressure-differential thrust of any entering propellants, and the momentum thrust of the nonaxial motion of the burning propellants within the combustion chamber. The misalignment moments from these variables are normally negligible because: (1) The magnitude of thrusts involved are very small relative to the exhaust jet thrust; and (2) the position of the injection nozzles, if any, and the direction of burning gases are normally designed to be symmetrical with respect to the design axial center line of the nozzle.

The second group of variables are those resulting in gaseous misalignment which, for the purpose at hand, can be defined as consisting of non-

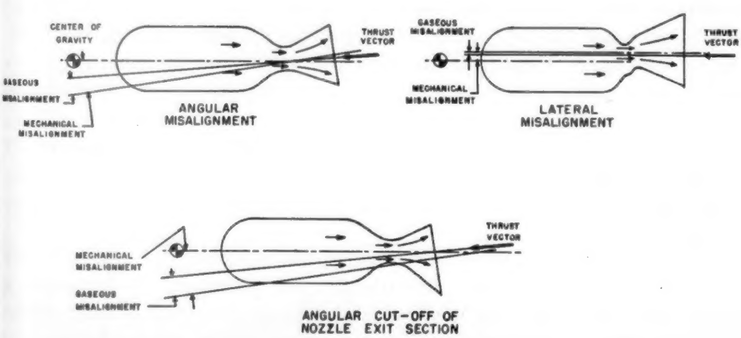

FIG. 3 GASEOUS MISALIGNMENT RESULTING FROM MECHANICAL MISALIGNMENT

uniform pressure, density, or speed of the exhaust gas at the exit section of the nozzle, and therefore a thrust vector which does not coincide with the perpendicular center line of the nozzle exit section. These variables are composed of: (1) Mechanical misalignment (nonaxial assembly) of the mechanical parts of the rocket motor; and (2) nonsymmetry of either the distribution of gases leaving the combustion chamber or of the mechanical parts of the rocket motor by such eccentricities as bulges and dents.

The first of these items, mechanical (nonaxial) misalignments, directly result in gaseous misalignments, as shown in Fig. 3. The relationship between these mechanical and gaseous misalignments depends upon the type of misalignments, the relationship of consecutive misalignments, the dimensions of the rocket parts, the degree of nozzle expansion (under or over expansion), and a good many other factors.

From the inertia properties of gases, however, it appears that these gaseous misalignments are normally in the opposite direction and of lower magnitude than the mechanical misalignments that originate them (Fig. 3). Thus, the effect of each mechanical misalignment in general is partially decreased by the effect of its resultant gaseous misalignment.

This conclusion permits measuring mechanical misalignments and taking their concomitant gaseous misalignments into account by simply recognizing that the combined mechanical-gaseous misalignment is less on the average (although not invariably) than the mechanical misalignment alone.

An estimate of the reduction could probably be made in each individual case at the expense of considerable detailed measurement and calculation, but does not appear merited.

The second source of gaseous misalignments—nonsymmetry of manufacture—can be expected to have a small effect since most rocket motors are designed to have radial symmetry, which is comparatively easy to maintain with conventional manufacturing procedures. However, an additional nonsymmetry can be introduced during firing by irregular burning or warpage. Misalignments from this latter source cannot be predicted for a given rocket type except by extrapolations of experimental data.

In summary, it appears that the significant sources of misalignment are (1) mechanical misalignments, including their subsidiary, partially-compensating gaseous misalignments, and (2) gaseous misalignments from nonsymmetry.

The latter are not predictable except from experimental data, and are frequently relatively small. Accordingly, the remainder of this paper is devoted to consideration of mechanical misalignments which are dependent upon specified production tolerances, and the means for predicting and reducing such misalignments.

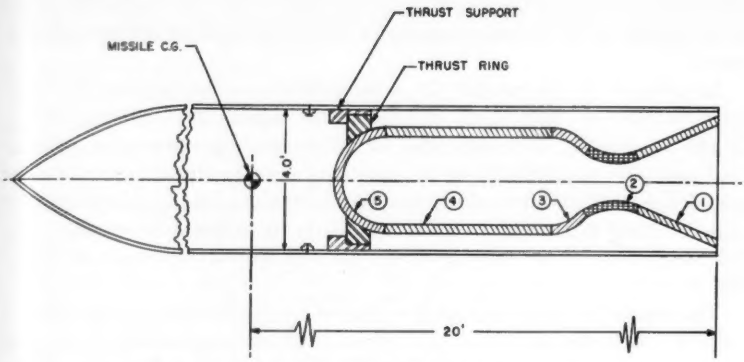

FIG. 4 LARGE ROCKET-POWERED MISSILE (SIMPLIFIED)

Mechanical Misalignments

The rocket missile is normally symmetrical with its center of gravity designed to lie on the center line of the missile. This center line is defined as the center line of the missile skin surrounding the center of gravity. A lack of coincidence of either the perpendicular center line of the nozzle exit section or the actual missile center of gravity with the design position of the missile center of gravity is therefore a direct measure of mechanical misalignment.

As noted earlier, mechanical misalignments result from manufacturing tolerances. A representative picture of the type of items to be considered can be gained from Fig. 4 showing a fictitious large rocket.

The mounting of the motor has been portrayed in simple fashion in order to reduce the number of details under discussion. The rocket motor is made of five sections. At the forward section of the motor, a thrust ring is mounted. This ring is supported and aligned by the thrust support carried by the missile skin and frame.

In counting the total possible sources of mechanical misalignment, it may be noted that the tolerances of each metal part in the chain between the nozzle exit section and the missile skin at the thrust support provide several sources of misalignment. If the parts of the rocket motor are assembled by using jigs to align the internal surfaces during a welding process, then there will be a minimum of misalignments. Three sources of misalignment will still be present for each part: (1) Lateral displacement of adjacent parts after welding; (2) angular displacement of adjacent parts after welding; and (3) lateral displacement of the center of the fore end of each part with the center of its aft end.

It should be noted that other techniques of assembly such as threaded joints would have involved other tolerances such as the external dimensions

of each part, or the relative angularity of the fore and aft surfaces of each part.

In addition to the roughly 21 misalignment possibilities for the seven parts between the nozzle exit and the missile skin at the thrust support, it is also possible for the missile skin at the center of gravity to be laterally and angularly misaligned with the missile skin at the thrust support. The missile center of gravity in turn may be misaligned with its adjacent missile skin. A total of approximately 24 misalignments is therefore possible. An instance where these misalignments all add arithmetically is shown in Fig. 5.

The possibility of a rocket such as that of Fig. 5 is evident. The question of how worrisome this situation is depends upon how probable it is. Obviously, if it happens only once in 1,000,000 motors, it will not merit concern. Accordingly, the probability of a given magnitude of misalignment must be determined before its undesirability can be judged. This is where statistical theory enters the picture.

Statistical Treatment

Ideal Statistical System: It will again be helpful to confine attention initially to an idealized system. Accordingly, it will be postulated for the sake of the initial statistical analysis that: (1) The dimensions of the various reproductions of each part follow a Gaussian—that is, a normal—distribution in magnitude and uniform distribution in angle; and (2) the specified production tolerances of each part denote the three standard deviation (3σ) limits of the distribution of sizes of that part.

In order to translate these concepts into conventional language, consider the distribution of the dimensions of a single part such as the diameters of 1000 reproductions of the thrust ring. Suppose that the diameter of this ring is specified as 34.000 ± 0.007 in. Since machining operations, particularly with human operators, are not exact but are influenced by

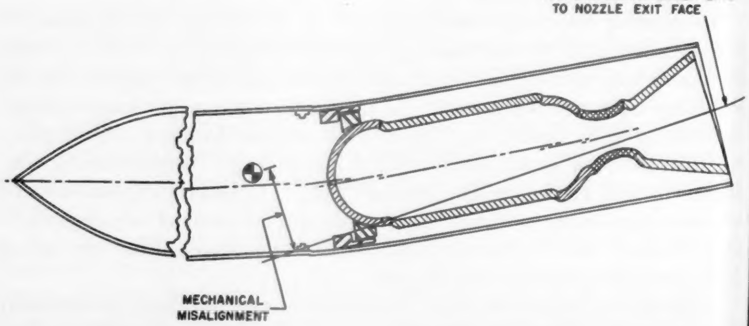

FIG. 5 ROCKET-POWERED MISSILE WITH ADDITIVE MISALIGNMENTS

random or chance effects, some variation in the diameter of the rings can be expected. If the diameters are measured to the nearest 0.0005 in., then the number of rings at each measured diameter will be something like that shown by the frequency bar chart in Fig. 6.

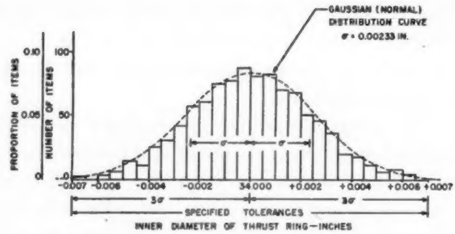

FIG. 6 FREQUENCY DISTRIBUTION FOR 1000 THRUST RINGS WHEN SPECIFIED TOLERANCES ARE EQUAL TO THE 3σ RANGE

Most of the items center around the specified mean dimension. The number of items of each dimension decreases rapidly as the distance from the mean increases, and soon approaches zero. Experience with mass-produced parts, and statistical theory both indicate that, if the variations are due solely to random effects, the envelope of the frequency bar chart usually approaches a normal or Gaussian distribution as shown by the dotted line. For both the frequency chart and the normal distribution curve, the included area between the horizontal axis and the upper limits over a given range of the horizontal scale represents the proportion of the total number of items. It thus represents the probability that an item chosen at random will fall within the corresponding range of values.

The mean of a distribution is defined as the arithmetic average.

$$m = \frac{\sum_{i=1}^{n} x_i}{n} \qquad [2]$$

where

m = mean of the distribution
x = value of each observation
n = total number of observations

The standard deviation, termed σ, is defined as the root-mean-square of the deviations from the mean

$$\sigma = \frac{\sqrt{\sum_{i=1}^{n}(x_i - m)^2}}{n} \qquad [3]$$

The standard deviation is a measure of the spread or scatter of the observations. For example, if great

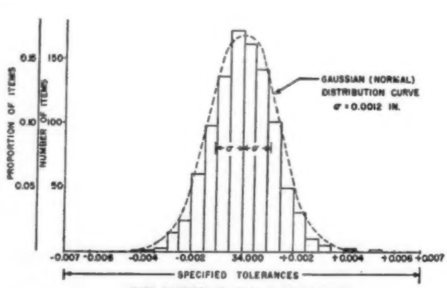

FIG. 7 FREQUENCY DISTRIBUTION FOR 1000 RINGS WHEN THE 3σ RANGE IS LESS THAN THE SPECIFIED TOLERANCES

care is taken in the manufacture of the thrust rings, then the distribution diagram would approximate that of Fig. 7. The distribution would have virtually the same mean as before, but less scatter and therefore a smaller standard deviation.

The great advantage of a normal distribution is that it is completely defined in terms of its mean and its standard deviation. For example, the probability that a random point will fall within 1σ of the mean is 68.2 per cent for all normal distributions. For a 3σ range on either side of the mean, the probability is 99.7 per cent. The 3σ range has received common acceptance among production quality control engineers as the range which, in the words of Gilbert and Sullivan, is "Never—well, hardly ever" exceeded by chance effects alone.

The successful experience with this practice is the reason that the 3σ range was chosen in the ideal system to coincide with the specified production tolerances. The 3σ range is undoubtedly not exactly correct for any one manufacturing situation but conforms in a broad sense to economical practice which dictates that just enough care be taken in production to insure that the specified tolerances are literally "hardly ever" exceeded.

Now that the distribution of dimensions for reproductions of a given part has been reviewed, it may be informative to see what happens when parts are combined. Consider for the sake of example the total misalignment obtained from the combination of parts containing four components of misalignment. The misalignment of each component can be represented by a vector (see Fig. 8) which varies in magnitude according to a normal probability distribution and which varies in angle according to a uniform probability distribution. The total misalignment is the vector sum and is represented by the closing vector from the origin representing the center line of the missile. For simplicity it will be postulated that

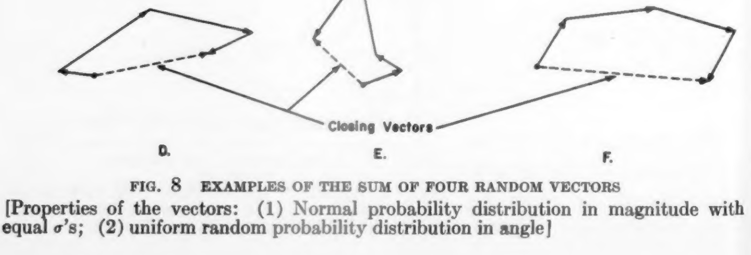

FIG. 8 EXAMPLES OF THE SUM OF FOUR RANDOM VECTORS
[Properties of the vectors: (1) Normal probability distribution in magnitude with equal σ's; (2) uniform random probability distribution in angle]

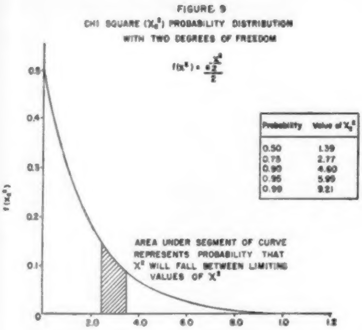

FIG. 9 CHI-SQUARE (χ_2^2) PROBABILITY DISTRIBUTION WITH TWO DEGREES OF FREEDOM

each of the component vectors has the same σ or production tolerance in terms of misalignment.

The component vectors can be of such magnitude and direction as to add up to a closing vector equal in size to the arithmetic sum of 3σ magnitudes for all four component vectors. The resulting closing vector would be an extremely rare occurrence since it would occur one time in 100,000,000 on the average. Less rare but still highly improbable is the possibility that the vectors add to virtually zero as in Fig. 8b and 8c. Most of the time, such as in cases 8d, 8e, and 8f, the closing vector will have a magnitude in the intermediate range. The problem thus resolves down to determining what proportion of the time—i.e., with what probability—each range of closing-vector values can be expected.

Fortunately, the complete probability distribution of the vector sum for the general case of n components can be derived by invoking some theorems from mathematical statistics. The proof is involved and only incidental to the purpose here. Accordingly, it will merely be demonstrated that the results are reasonable. The theoretical derivation is appended for those who are interested.

The statistical theory indicates that the probability distribution of the net misalignment $p(M)$, is given by

$$p(M) = \sigma_T(\chi_2^2)^{1/2} \qquad [4]$$

where $\sigma_T^2 = \sigma_1^2 + \sigma_2^2 + \ldots . \sigma_n^2$ and $\sigma_1, \sigma_2, \ldots, \sigma_n$ are the respective standard deviations for the n component misalignments, and χ_2^2 represents the chi-square probability distribution with two degrees of freedom.

That is, the magnitude of a misalignment at a given probability level is equal to σ_T times the square root of χ_2^2 at the same probability level. For example, χ^2 has a 99 per cent probability of being equal to or less than 9.21. Then the magnitude of the misalignment has a 99 per cent probability of being equal to or less than $\sigma_T\sqrt{9.21}$.

The values of χ^2 at various probability levels are available from conventional statistical tables and are shown in Fig. 9 and Table 1. The nature of the probability distribution of net misalignment is shown in Fig. 10 for a σ_T equal to 1.0. It may be noted

TABLE 1

Probability of inclusion	χ_2^2
0.99	9.21
0.95	5.99
0.90	4.61
0.75	2.77
0.50	1.39

that the distribution of net misalignments agrees in principle with the earlier reasoning from Fig. 8.

Real Statistical System, Sample Problem: Recall that the prior statistical analysis is based upon an ideal system and is not exact for real systems. Perhaps the usefulness and the limitations of the analysis can best be appreciated if it is applied to an actual misalignment problem.

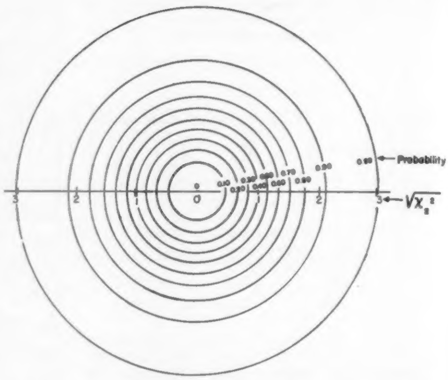

FIG. 10 PROBABILITY DISTRIBUTION OF NET MISALIGNMENT VECTOR, $\sigma_T = 1.00$

Ideal Statistical Model: Consider the large rocket of Fig. 4 in the light of the theory proposed thus far to see what can be said about the probability distribution of the total mechanical misalignment if it has a simplified set of specified mechanical tolerances as in Table 2.

The table also shows the corresponding standard deviation σ for each misalignment when its corresponding specified tolerance is taken equal to the 3σ range. Recall that the standard deviation of the total misalignment is given by $\sigma_T^2 = \sigma_1^2 + \sigma_2^2 + \ldots, \sigma_n^2$.

TABLE 2 SPECIFIED TOLERANCES AND CORRESPONDING STANDARD DEVIATIONS OF THE RESULTING POSSIBLE MISALIGNMENTS

No.	Item	Tolerances: Lateral, in.	Tolerances: Angular, deg	σ, in.
1	Lateral location of missile center of gravity relative to the center line of the missile	±0.060	...	0.02
2	Lateral location of center line of missile skin at center of gravity relative to the center line at the rocket thrust ring	±0.050	...	0.017
3	Angularity of center line of missile skin at center of gravity with the center line at the rocket thrust ring	...	±0.020	0.028[a]
4–10	Lateral alignment of the center line of the fore face of each part with the center line of the aft face	±0.010	...	0.0033
11–17	Lateral alignment of adjacent sections after being welded together or otherwise joined	±0.010	...	0.0033
18–24	Angularity of adjacent sections after being welded together or otherwise joined	...	±0.010	0.014[a]

[a] Calculated for a distance of 20 ft between nozzle exit face and missile center of gravity.

TABLE 3 STANDARD DEVIATION OF GROUPED MECHANICAL MISALIGNMENTS

Items in Group (From Table 2)	Grouped Misalignment	σ, in.
1–3	Location of missile center of gravity relative to the center line of missile at the rocket thrust ring	0.0387
4–17	Lateral alignment after assembly of center of nozzle exit face with missile center line at rocket thrust ring	0.00466
18–24	Angular alignment after assembly of perpendicular center line of nozzle exit face with missile center line at rocket thrust ring	0.014
All	Over-all grand total, σ_T	0.0412

Incidentally, this relationship also holds true if component σ's are grouped according to type to obtain a measure of the relative importance of the various types of variables. This is shown in Table 3.

It may be noted from Table 3 in passing that because of the root-mean-square relationships, small misalignments tend to have a negligible effect. For the tolerances under consideration, the influences of the lateral tolerances of the motor itself are completely insignificant. Angular tolerances of the motor have a minor effect, while the location of the missile center of gravity relative to the missile center line at the point of rocket attachment is dominant.

Hence, on the basis of this information alone, the lateral tolerances on the motor could be relaxed appreciably without noticeable penalty. In addition, if it is concluded that mechanical misalignments should be reduced, emphasis would be concentrated on the production practices which determine the position of the missile center of gravity with respect to the motor mount. A more thorough approach would be to devise some method of controlling over-all misalignment of groups of parts, or better still, of the entire missile.

However, to resume the quest for the probability distribution of the total mechanical misalignment, only the over-all standard deviation, 0.0412 in., in the probability relationship stated earlier need be considered:

$$P(M) = \sigma_T(\chi_2{}^2)^{1/2} \quad \text{[5]}$$

By using values of $\chi_2{}^2$ from Table 1, Table 4 can be constructed to the desired relationships. The maximum possible mechanical misalignment based upon simple arithmetic addition of all tolerances has been included for comparison.

TABLE 4 PROBABILITY OF TOTAL MISALIGNMENTS

Probability of not exceeding maximum misalignment	$\chi_2{}^2$	Maximum misalignment, in.
$1-10^{-37}$	...	0.628[a]
0.99	9.21	0.125
0.95	5.99	0.10
0.90	4.61	0.088
0.75	2.77	0.069
0.50	1.39	0.048

[a] By simple arithmetic addition of all tolerances.

It can therefore be concluded that although a total mechanical misalignment of 0.628 in. is possible within specifications, 99 per cent of the time the mechanical misalignment would not exceed 0.125 in. Similarly, 90 per cent of the time, the misalignment will remain below 0.088 in., 50 per cent of the time, below 0.048 in., etc.

Modifications Required for a Real Statistical Model: Thus far, the analysis of the real rocket has been based upon the ideal statistical model. It is now appropriate to examine the conclusions reached thus far to see how they should be modified in view of the deviations of the real rocket from the ideal statistical model. The following deviations from the ideal statistical model deserve consideration:

1 The distribution of the critical dimension of each component part may not be exactly Gaussian (normal). This fact conceivably threatens the validity of the root-mean-square addition of σ's.

In actuality, however, a small deviation from normality, as is probable, will introduce only a small error. Moreover, it is a theorem of theoretical statistics that the distribution of the sum of several nonnormal distributions approaches the properties of the sum of normal distributions. Since the situation at hand involves the sum of many distributions, it may be safely concluded that the principle of root-mean-square addition of σ's is applicable.

2 The specified tolerances may not correspond exactly to the 3σ range of the distribution of dimensions of each part. If this deviation from theory is consistent throughout, it will introduce a directly proportional error in the conclusions.

If the deviations from 3σ are randomly inconsistent they will tend to cancel. As was noted earlier, there is a strong economical incentive for the tolerance limits to mark the "hardly ever" range of production parts. Whether this range in any given situation corresponds to the 3σ range can only be determined by measurements of the parts from the actual production situation.

3 The distribution of the component parts may not have a uniform distribution in angle—i.e., may not be radially symmetrical. This possibility threatens the validity of the χ^2 distribution of the total distributions.

It is possible that certain types of assembly jigs will introduce misalignments in the assembly of radially symmetrical parts which are not random in angle, but which consistently occur along certain angles. Fortunately this effect like the lack of normality is washed out when several sources of deviation are present. It can therefore be safely concluded that application of the χ^2 distribution is valid. All in all, it appears that consideration of the deviations of the real system from the ideal statistical model does not disclose significant inaccuracies and does not change conclusions in principle or in order of magnitude. It does indicate that without data on manufacturing precision of each individual manufacturing process, the

conclusions from the ideal statistical model may not be assumed to be highly precise.

Over-all Evaluation: Thus far, the analysis of the sample rocket has led to the conclusions that the probability distribution of the mechanical misalignment will be on the order of the values discussed earlier, and shown in Table 4. The total mechanical-plus-gaseous misalignment will be larger or smaller than the mechanical misalignment depending upon whether or not the additive gaseous misalignments from nonsymmetry exceed the compensating gaseous misalignments originating from the mechanical misalignments.

The probability distribution of gaseous misalignments can be determined for a given rocket vehicle only by experiment. In general it is expected that the net gaseous misalignment will be of the same order of magnitude or smaller than the mechanical misalignment. In accordance with the theory presented earlier, the standard deviation for the distribution of the total misalignment is the root-mean-square sum of the σ's for the mechanical and gaseous misalignment distributions.

When the distribution of the total misalignment has been determined, some decisions must be reached about (1) the maximum permissible misalignment, and (2) the probability (relative frequency of occurrence) that is acceptable for the maximum permissible misalignment.

The maximum permissible misalignment will depend upon the design and application of the rocket vehicle. Variables such as aerodynamic stability, size of target, roll rate of vehicle, type of guidance, total time of flight, and total rocket impulse, will dictate permissible misalignment.

The acceptable probability of permissible misalignment is largely dependent upon the application and the manufacturing difficulties involved. Thus, a short range bazooka missile might be quite satisfactory under production conditions which resulted in a 90 per cent probability of satisfactory alignment. On the other hand, a large, extremely expensive sounding rocket might require the added manufacturing expense of insuring better than 99 per cent probability of a satisfactory alignment. In some cases, the probability of a successful flight will vary with the magnitude of the misalignment, which in itself follows a probability distribution. Determination of the optimum values of the permissible misalignment in such instance would therefore depend upon the analysis of a joint or three-dimensional probability function.

Conclusions

The foregoing analysis has led to the following major conclusions:

1 Jet misalignment arises from mechanical and gaseous misalignments which stem from nonaxial and nonsymmetrical manufacture.

2 The relative effect of individual sources of mechanical misalignment can be estimated by adding their specified tolerances according to root-

mean-square sums. This results in numerous small tolerances having a negligible effect while a few large tolerances can have a relatively predominant effect.

3 Over-all misalignments are reduced when assembly alignments are controlled for groups of parts, rather than for individual parts. Lowest misalignment is obtained if direct control of over-all misalignment is incorporated in the manufacturing assembly procedure.

4 The proposed statistical method of assessing the probability distributions of total jet misalignment yields values at the various probability levels which are probably correct in relation to each other. For more precise conclusions, experimental observations on the probability distributions of dimensions of the manufactured parts and on the average order of magnitude of gaseous misalignments are required.

Appendix

Theoretical Deviation of the Probability Distribution of the Vector Sum of n Random Vectors:

Given n random vectors $r_1, r_2, \ldots, r_n$ with probability distributions such that:

1 The lengths of the vectors follow Gaussian distributions with means $m_1 = m_2 = \ldots, m_n = 0$, and variances $\sigma_1, \sigma_2, \ldots, \sigma_n$.

2 The angles of the vectors follow uniform, random distributions. Then, from the generalized central limit theorem, the vector sum R of the n vectors will be a random variable such that its projections, x and y, on any two arbitrary, mutually perpendicular planes, X and Y, respectively, will follow independent Gaussian distributions defined by

$$m_x = m_y = 0 \qquad [6]$$

$$\sigma_x^2 = \sigma_y^2 = \sigma_1^2 + \sigma_2^2 + \ldots, \sigma_n^2 \qquad [7]$$

From geometry, $x^2 + y^2 = R^2$.

Hence the distribution of R^2 is the sum of the squares of two independent Gaussian distributions. However, the sum of the squares of two standard normal deviates is a chi-square (χ_2^2) distribution with two degrees of freedom.

By definition, x/σ_x and y/σ_y are standard normal deviates. Hence

$$\left(\frac{x}{\sigma_x}\right)^2 + \left(\frac{y}{\sigma_y}\right)^2 = \chi_2^2$$

But $\sigma_x = \sigma_y$. Hence,

$$\left(\frac{R}{\sigma_x}\right)^2 = \left(\frac{x}{\sigma_x}\right)^2 + \left(\frac{y}{\sigma_x}\right)^2 = \chi_2^2$$

and

$$R^2 = \sigma_x^2\,\chi_2^2$$

whence

$$R = \sigma_x(\chi_2^2)^{1/2}.$$

ROCKET-ENGINE FLIGHT TESTING

By Richard F. Gompertz

Aeronautical Rocket-Propulsion Engineer, Power Plant Branch, United States Air Force, Edwards Air Force Base, Muroc, Calif.

A rocket-engine flight-test project is described. The necessity of obtaining better engine instrumentation during flight is stressed. Rocket-engine preflight check, propellant servicing, the rocket-powered phase of a flight-test project, and postflight procedures are outlined, as presently conducted at an Air Force experimental flight-test base.

Test Program

HIGH-SPEED flight, conducted at altitudes heretofore never attempted, has opened up a new chapter in the history of aircraft power plants. Many patronizing and dubious thoughts have been dispelled in the minds of those who considered the rocket engine "a temporary invention with the primary purpose of scaring those who might be present during an operation of a rocket-propelled missile, or of doing away with the unfortunate persons who happen to be present when the missile strikes the target."

Not too many years ago, consideration of a rocket engine as a sole power plant for aircraft-flight propulsion, especially for piloted aircraft, would have put the proponent of such an idea into the category of the advocate of the human cannon ball.

Scientific requirements and military necessity, however, have changed the aircraft-propulsion picture greatly in the past few years. Rocket-engine designers were confronted with the problem of building engines which could be turned off during flight, throttled and restarted—in short, perform according to accepted reciprocating and jet-engine standards and at the same time provide optimum operational safety to prevent mishaps to pilot and aircraft.

When comparing a missile-rocket power plant to a piloted-aircraft rocket engine, one may readily visualize the vast difference in design requirements. Roughly speaking, it is safe to say that operational engine life in terms of minutes may be adequate for most missile power plants, and immediately after the exhaustion of the rocket propellants, the only further consideration to be given to the engine is the dead weight.

Since December, 1946, the United States Air Force X-1 aircraft have made many successful rocket-powered flights in the United States, using the same engine on successive flights. It is the purpose of this paper to

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Presented at the 1950 Annual Convention of the American Rocket Society, Hotel Statler, New York, N. Y., Nov. 30–Dec. 1, 1950.

give an account of the factors involved in conducting a flight-test program on a rocket-propelled aircraft.

Instrumentation Requirements

Practically all flights that have been conducted on rocket-propelled aircraft have been for the purpose of obtaining performance or other aerodynamic data on the airplane. On these tests the general practice is to accept the performance of the thrust unit as it is specified by the manufacturer and proved by ground tests. Because of the emphasis that has been placed on the requirement for data to evaluate the airplane, and because of the severe shortage of available instrumentation space, the in-flight evaluation of the rocket-engine characteristics has been almost wholly neglected on the programs that have been conducted to date. The fact cannot be disputed that the availability of an aircraft specifically for the purpose of doing rocket-power-plant research would materially assist in obtaining additional information of great value to the engine-development program. Certain low-temperature phenomena, affecting the specific impulse of the rocket propellants, acceleration forces of the type encountered only during actual flight tests which result in the interruption of the propellant feed, and many other phenomena which result from flight maneuvers, have never been successfully simulated during a static ground test. Neither have they been thoroughly investigated by adequate instrumentation during flight.

As a result, ground installations and well-instrumented test cells are of

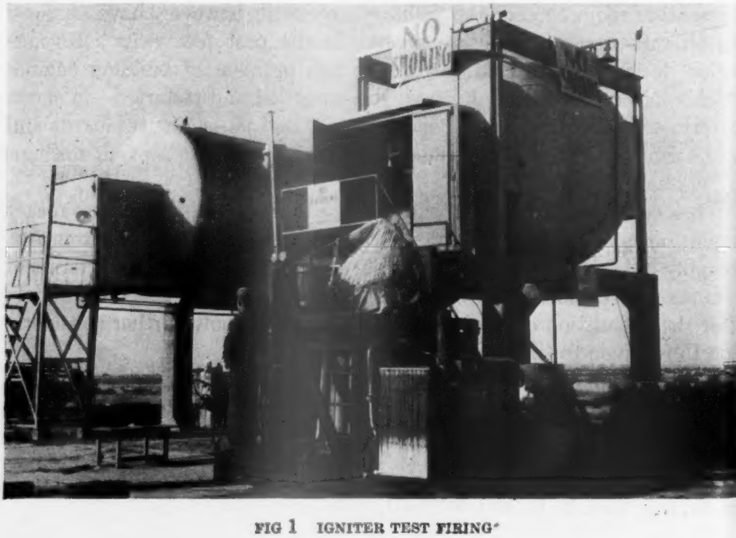


FIG 1 IGNITER TEST FIRING

utmost importance to the success of a rocket flight-test program. The use of special test devices and test instruments, some of which have required a considerable expenditure of funds, has greatly contributed to the safe performance of rocket-engine flight-test projects. A thorough ground-test program augmented by basic safety features which shut off the engine automatically in case of malfunction and good pilot procedures have resulted in a record of no accidents chargeable to engine difficulties during the three and one-half years of operation.

Experience to this date indicates the desirability of eliminating all instrumentation from the cockpit panel not directly needed by the pilot during flight. Hence, basic cockpit instrumentation should include only chamber pressure, tank pressure, source pressure, propellant-tank-level indication, and control-pressure gages for the pneumatically operated valves. Basic electrical instrumentation is necessary to assure the pilot of the functioning of the electrically operated valves, switches, and solenoids. Standard aircraft instruments using a 24-volt supply are adequate for this purpose.

The meager engine data that have been recorded during aircraft-evaluation flights have proved to be valuable in contributing to analysis of engine difficulties. It is quite easy for the pilot to overlook the pressure readings on the chamber pressure gages during the ignition period when they are critical. Photopanel records, however, show small pressure differentials and indicate rates of change of these pressures during a period when the time element is an important factor.

Telemetering of flight data is also useful but, unfortunately the power-plant engineer is again the last man on the list to receive consideration in the assignment of the limited number of intelligence channels available. Atmospheric disturbances, malfunctioning of telemetering equipment, and the high cost of telemetering equipment have also contributed in the past to a tendency to rely on internal recorders.

The pilot's report during and after each individual flight is always a valuable source of information. Certain phenomena and sound effects inherent in rocket-engine operation cannot be properly interpreted by any instrumentation; whereas, an experienced pilot can often contribute the missing link to the solution of a difficult problem. Care should be taken to make a permanent record of the pilot's flight report transmitted by radio and recorded by wire or tape recorder.

Preflight Procedure and Servicing

A statement made a long time ago that a flight-test program is only as good or as bad as the supporting ground facilities and the availability of special equipment certainly holds true for a rocket-aircraft test program. Much of the required special equipment is usually unavailable at the begin-

FIG 2 LIQUEFIED-GAS SERVICING SITE FOR ROCKET-PROPELLANT AIRCRAFT

ning of the first test phase, and for the remainder of the project, the rocket engineer is generally plagued with many makeshift devices which were designed, built, and assembled on the spot as a matter of necessity. It is of importance, therefore, to have highly skilled and specially trained personnel available, and to have ready access to information regarding engine modifications which might require extensive changes in ground-test equipment or flight instrumentation.

The preflight-test procedure varies somewhat, depending on the results of the postflight inspection of the engine. In all cases and independent of previous flights, a complete pressure check is made which consists of filling the propellant tanks with nitrogen, operating all valves and pressure switches through the electrical circuits from the cockpit, and searching carefully for leaks or discrepancies. Considerable experience is required to perform this check as the observation of the engine and its components in the aircraft is difficult, mainly because access doors are small and insufficient in number. Great care is taken to trace all leaks to their places of origin, a most helpful method being the application of a water-soap solution to all fittings and connections. A leaky fitting cannot be tolerated and may require removal of the engine from the airplane, or rework or replacement of the faulty part in the shop.

An igniter-firing test is the second important function during the rocket-engine preflight check. In the past a high percentage of hard starts or failures to start were traced directly to faulty igniter operation.

To prove the ignition system and guarantee its operation, special ignition-test devices have been developed which contain a small amount of rocket propellants which would be introduced into the engine during actual ignition. This operation is not considered hazardous and is therefore conducted near the aircraft hangar with the rocket-engine cylinder nozzle

pointed into the open. From a distance of 40 to 50 feet, the ignition flame can be observed distinctly in each combustion chamber; the shape of the flame, the color, and the sound of combustion are valuable clues to the experienced rocket-engine mechanic.

The electrical checks are usually performed by the aircraft crew; since a great deal of time and care is devoted to the flight instrumentation, final electrical checks are continued almost up to the time of flight.

A continuous visual inspection is conducted at frequent intervals up to and during the time of propellant servicing to insure that no foreign matter, dirt, or dust particles, enter exposed openings, especially propellant-servicing connections.

The order of propellant servicing consists of nitrogen first, alcohol second, and liquid oxygen last. The nitrogen is required to pressurize the propellant tanks and to operate all pressure-controlled valves, such as the main propellant shutoff valves. Another and most important function of the nitrogen is to provide a constant bleed through the propellant valves and combustion chambers in order to avoid or neutralize any leaks which may develop internally.

At a flight-test base, nitrogen is usually stored in liquid form and is passed through a converter and transformed into a high-pressure gas. This gas is then expanded into the high-pressure storage system of the aircraft. In case of a pressurized feed system wherein the propellants are expelled from the tanks solely by gas pressure, a considerable quantity of high-pressure nitrogen has to be carried aboard.

The water-alcohol fuel is pumped into the fuel tank by conventional methods, similar to gasoline or JP-3 fueling procedures. To expedite propellant servicing, it is customary to start the filling of the fuel soon after sufficient pressure is available in the aircraft nitrogen-storage system to operate the various valve functions and safety features.

Liquid oxygen is filled last and is scheduled to be completed as nearly as possible to the time of take-off of the aircraft to minimize evaporation losses. The oxygen tank and the main oxygen propellant lines are insulated in the X-1 aircraft. Evaporation losses, however, are still considerable if the time of departure is unduly delayed.

It is considered good practice to keep the nitrogen-supply line to the X-1 aircraft connected to the nitrogen source until the last minute in order to replace the nitrogen lost through the engine-bleed system which is continually in operation once the servicing of the propellant tanks is begun.

The last check is performed by the airplane crew who assure that all filling caps are tight, and that the liquid-oxygen tank-vent valve opens and closes without freezing.

The Powered Phase of a Rocket Aircraft Flight Test

The X-1 aircraft is primarily a research vehicle designed to obtain data

at extreme altitudes and speeds. A specifically modified B-29 or B-50 is provided to lift the X-1 to a higher altitude for launching, where the advantages of rocket propulsion can be employed more readily than by means of a ground take-off.

The main modification of the mother aircraft consists of a considerably enlarged bomb bay opening to accommodate the X-1 aircraft which is suspended from a standard bomb shackle and secured in place prior to all propellant-filling operations.

At the completion of all propellant servicing, the mother aircraft and attached X-1 are ready to take off and climb to the altitude required for the drop. During the ascent, the X-1 pilot climbs from the mother airplane into the cockpit of the X-1 aircraft, and keeps in constant radio contact with the crew of the mother airplane and the ground stations that will monitor all radio transmission throughout the flight.

Shortly before attaining the required altitude, the crew aboard the mother airplane disconnects the nitrogen topping line which has been feeding nitrogen into the X-1 aircraft steadily from the auxiliary tankage in the parent aircraft to replace the nitrogen gas lost through the engine bleed system. At present, however, the capacity of the internal nitrogen topping system installed in the mother aircraft cannot replace the nitrogen gas lost through the engine-bleed system over a period of time extending beyond that necessary to attain drop altitude.

Upon reaching drop altitude, the pilot is advised to pressurize the propellant tanks. This is accomplished by pressuring the fuel tank first and the oxidizer tank last to reduce gasification and evaporation losses in the liquid-oxygen system. Prior to the drop, the X-1 pilot bleeds the propellant system, primarily the liquid-oxygen lines of all trapped gases and vapors, thereby assuring that oxygen will flow in the liquid state when injected into the combustion chambers. This operation is completed thirty to sixty seconds prior to the drop of the X-1 aircraft from the mother airplane.

The imminent drop is signaled by the copilot of the mother airplane who counts off the last few seconds before pulling the release:"...7-6-5-4-3-2-1—drop!" Seconds later, "Number one O.K." is signaled as the first chamber is ignited. A tiny white speck marks the beginning of a vapor trail which shows a slight surge or deformation as each successive chamber is ignited.

The flight program may call for firing all cylinders, or it may be sufficient to fly on two or three cylinders only. Ground observation is limited, however, to the determination of starting or stopping points only of individual cylinders which are marked by the change in the vapor-trail pattern. Thus, the pilot's radio reports provide the best source of flight-progress information, giving indications of ignition pressures, chamber pressures, control pressure settings, and possible malfunctions.

During flight, the pressure-fed rocket engines usually require adjustment of the pressure regulators to increase tank "loading" pressure while the propellants are being expelled. The pilot watches the oxygen and fuel-tank pressure gages, making sure that the fuel-tank pressure remains from 10 to 15 psig above the oxygen-tank pressure. Thus, a slightly rich propellant-mixture ratio is obtained which considerably increases combustion-chamber life and avoids hard starts and shutdowns at a very slight decrease in specific impulse.

If a shutdown is intentional or is a result of the operation of the emergency-shutdown system, the engine can be restarted by the pilot. Not more than one cylinder is started at any one time, and for the same reason, only one cylinder at a time is shut off to keep hydraulic surges and propellant hammer to a minimum.

It is considered better practice to shut the rocket engine off before all of the propellants are exhausted rather than rely on the pressure-switch-operated automatic shutdown.

The pilot ordinarily jettisons the remaining propellants after engine shut-off; normally one propellant at a time to decrease the danger of external ignition. Both propellant tanks are then vented of all pressure, but no propellant purging can be attempted at this time inasmuch as nitrogen is expelled through the vent valves; hence no propellant residues can be purged from the tank and lines during flight.

The propellant jettisoning completes the powered phase of the flight. The remainder of the flight is conducted as a glider and terminates in a power-off landing on the dry lake bed.

The Landing and After-Flight Procedure

At the end of the landing roll, the fast and powerful X-1 rocket aircraft, which can perform second to none in the air, is now entirely dependent upon ground equipment and ground personnel. A jeep is specially equipped with a towing fork and is used to tow the X-1 aircraft to the nitrogen-gas servicing area to complete the purging operation which could not be conducted in the air because of the previously explained limited amount of nitrogen gas in the airplane.

To minimize hazardous conditions, rocket engines must be thoroughly dried and cleaned internally at the completion of each test. It is also a good practice to remove all of the water-alcohol fuel from the system to reduce the corrosive action. A thorough inspection of all visible parts of the engine is made, and combustion chambers are examined for bulges or possible burn-outs. A pressure check is conducted similar to the pre-flight check in cases where malfunction of pressure-operated accessories has been reported during the flight.

Conclusion

It is often said that the worries of the rocket engineer during the flight phase of a project are great, but short-lived. Most firing durations of rocket engines are still matters of seconds or several minutes at best. Seconds have been known to turn into hours, however, when difficulties in the air were encountered and when the pilot's flight report contained terse information spelling trouble concerning engine operations.

It is indeed a high tribute to the pilots, the maintenance personnel, the manufacturers of the rocket power plant and the X-1 aircraft, that after three and one-half years of intensive flight testing not a single serious accident has occurred.

The road ahead is long and difficult, but no one will deny that progress in rocket propulsion has been gratifying. Many will still remember when so-called "rocketeers" crouched behind sandbags and counted time after some brave soul lit the fuse and literally had to run for his life. Protection for personnel and equipment against the hazards of engine failures and explosions have made steady improvement. The responsibilities of personnel connected with rocket-engine-flight testing are not limited only to the engine phase of a flight-test project, but are closely tied to the design and development of better and safer ground-test equipment.

Cumbersome test devices and procedures presently considered necessary to conduct a safe rocket-flight test are certain of becoming more streamlined in the future. Improved rocket engines, requiring less maintenance and less attention by the pilot and comparing favorably in service life with existing jet engines, are presently in the development stage.

The lessons learned from the X-1 project have certainly encouraged planning and engineering personnel of the services and power-plant contractors to develop rocket engines of higher thrusts, longer durations, and increased reliability.

ADJUSTING THE IGNITER TEST CART

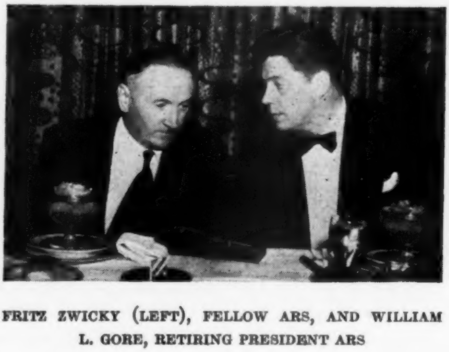
FIFTH ANNUAL CONVENTION OF THE AMERICAN ROCKET SOCIETY

MORE than 500 members and guests participated in the Fifth Annual Convention of the American Rocket Society held at the Hotel Statler, New York, N. Y., Nov. 26–Dec. 1, 1950, in conjunction with The American Society of Mechanical Engineers.

The large attendance at each of the three technical sessions, at which 12 papers covering theory, operation, testing, and design were discussed, was ample evidence that the ARS was providing technical leadership in the fields of rockets and jet propulsion. The Honors Night Dinner held on Thursday, Nov. 30, gave members from the various ARS sections an opportunity to honor men who have made significant contributions to rocket research and those who have contributed to the work of the Society.

The ARS registration desk in the ballroom foyer was the focal point for members and guests of the Society. Here members met the ARS staff, brought their Society records up to date, inspected a fine collection of books and papers assembled for their convenience, and exchanged information on how ARS could better serve its members.

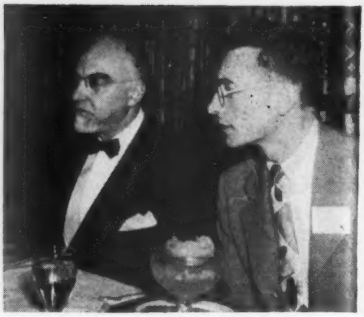
For the Honors Night Dinner, members gathered early on the top floor of the Hotel. Before the dinner began many were introduced to Society officers and honored guests as they arrived. Following an excellent dinner, William L. Gore, retiring president of the ARS, began the honors ceremonies by introducing the guests seated on the dais. They were: Laurance Rockefeller, president, Rockefeller Bros.; Rear Admiral A. M. Pride, chief of Bureau of Aeronautics; Mrs. Esther Goddard, widow of Dr. Robert H. Goddard, pioneer in rocket research, and herself an Honorary Member of the ARS; G. Edward Pendray, senior partner, Pendray and Company; Clair M. Beighley, 1950 Student Award winner, research assistant, Purdue University; C. N. Hickman, Atomic Research Laboratory, Sandia Base, N. Mex., in whose honor the C. N. Hickman Award is given each year; Lovell Lawrence, Jr., winner of the 1950 Goddard Memorial Award, and president of Reaction Motors, Inc.; E. C. Uhl, chief engineer, Glenn L. Martin Company, who represented Col. Leslie A. Skinner, USAF, winner of the 1950 C. N. Hickman Award; Fritz Zwicky, Fellow ARS, tech-



FRITZ ZWICKY (LEFT), FELLOW ARS, AND WILLIAM L. GORE, RETIRING PRESIDENT ARS

Courtesy of The News, New York

LOVELL LAWRENCE, JR. (LEFT) AND H. R. J. GROSCH, INCOMING PRESIDENT ARS



G. EDWARD PENDRAY (LEFT), FELLOW ARS, WITH CLAIR M. BEIGHLEY, CO-WINNER ARS 1950 STUDENT AWARD

nical director of Aerojet Engineering Corporation, and banquet speaker; and Under-Secretary of the Navy Dan A. Kimball.

Mr. Gore then introduced the members recently honored by election to the Fellow grade of ARS membership. He asked each to come to the dais to receive his certificate. The men so honored are: Frtiz Zwicky, M. J. Zucrow, G. Edward Pendray, Louis G. Dunn, and Rear Admiral Calvin M. Bolster.

Proceeding to the presentation of 1950 honors, Mr. Gore called Mr. Beighley to the center of the dais where he presented him with the 1950 ARS Student Award. Eldon L. Knuth, co-winner of the award was not able to be present to be honored with Mr. Beighley. Mr. Knuth is a Guggenheim Fellow at the California Institute of Technology, Pasadena, Calif. The award was given for their paper "Film Cooling of Rocket Motors," which was judged to be the best paper by student members submitted to the 1950 Awards Committee.

Mr. Gore next called on Mr. Uhl to accept the C. N. Hickman Award for Col. Leslie A. Skinner, who could not be present because of serious illness in his immediate family. The award honors Col. Skinner for "outstanding vision and achievement in the development and application of weapons utilizing the solid-propellant rocket; his participation in the establishment of a military requirement for an antitank rocket which led to the successful development and use of the famed bazooka in World War II and for his continued foresight in clearly designing future military weapons which utilize the solid and liquid rocket engine for their propulsion." Mr. Uhl is co-holder of the original bazooka patents.

The Robert H. Goddard Memorial Lecture Award for 1950 was presented to Lovell Lawrence, Jr., president, Reaction Motors, Inc., Dover, N. J., for "initiative and vision in the conception, research and development of liquid-rocket power plants; his diligent supervision of the development

of liquid oxygen-alcohol rocket engines by Reaction Motors, Inc.; for leadership in those difficult years during which breadboard models of liquid rocket engines were transformed into dependable, safe, high-performance prime rocket power plants for the XS-1, the Navy D-558 and the Navy Viking Sounding Rocket; and in consideration of his untiring efforts to aid and assist in the successful solution of problems intrinsic with rocket power plants for propulsion." The Award was presented by Mrs. Esther Goddard whose late husband it memoralizes.

Biographical sketches of the ARS Fellows and Honors recipients will be found on pages 187–194.

Next year, Mr. Gore announced, the American Rocket Society will present an additional award. It will be known as the G. Edward Pendray Award to be given to an author for a significant contribution to the technical literature on rockets or the general field of jet propulsion.

Mr. Gore then introduced Dr. Zwicky, the main dinner speaker.

Morphological Thinking

A new method of thought called "morphological thinking" was recommended as a tool for scientists and inventors by Dr. Zwicky in his talk "Tasks We Face." The method concerned the form and the content of thought. Its goal was "the visualization and analysis of all possible solutions of any given problem without regard or reference to standards of value." Its prime virtue, Dr. Zwicky added, was that it opened up "vistas" to the inquiring mind—vistas "which remain hidden to unorganized thought which leaves invention to chance."

Dr. Zwicky described his morphological method as follows: First an exact statement of the problem to be solved is formulated. In the second step a study is made of all significant parameters pertaining to the problem. In the third step each parameter is broken down into "independent irreducible elements" and the symbols for parameters and the element are arranged to form a "morphological box." If one element in each of the parameter groupings is encircled and these connected into a chain of circles, the result will be one possible solution to the original problem. In this step of the method, Dr. Zwicky warned, it was "exceedingly essential" that no questions be asked as to what value one or the other of the solutions might have. Premature curiosity almost always defeats unbiased application of the method.

When all possible solutions are determined, step four is taken. This is the determination of performance values of the derived solutions on a universal and necessarily simplified basis.

The fifth and last step, he said, was the choice of particularly desirable special solutions and the working out of the solutions in practical detail.

Inherent in the morphological method, Dr. Zwicky cautioned, was the

(LEFT TO RIGHT) ROBERT R. DEXTER, MRS. ESTHER GODDARD, AND S. PAUL JOHNSTON

conviction that all solutions could be realized in actual practice even though some among the solutions to which an inquirer was led may turn out to be relatively trivial.

Types of Problems

There were three types of generic problems which the morphological analysis attempts to solve: (1) How much information about a certain limited set of phenomena can be obtained with the help of a given class of devices; or, stated differently, what devices are necessary to obtain all of the information about a given set of phenomena? (2) What is the sequence of all effects issuing from a certain cause? (3) Deduce all of the devices of a given class, or all of the methods of a given class, or all of the solutions of a given definite problem.

As an example of a class (3) problem Dr. Zwicky referred to the problem of determining the totality of all jet engines which are composed of simple elements and activated by chemical energy. He said that historically this was the first problem to receive systematic and complete morphological analysis. This problem was given priority because of German jet-propulsion superiority at the beginning of the war and the need for American science to "bridge the gap." A simplified analysis resulted in the tabulation of 576 jet engines composed of simple elements. The morphological box on jet engines contained 11 parametric groupings, each with two to four elements, adding up to 30 elements, the combination of which made possible 36,864 pure medium jet engines containing single simple elements only and using chemical energy. Because of internal contradictions this number was cut down to 17,280 possible simple engines.

Commenting on some of the results of the jet-engine study, Dr. Zwicky predicted that it would be possible eventually to make ductlike motors swallowing up components of the upper atmosphere and expelling them at greater and greater speeds, thus extracting its propulsive power from the atmosphere. Such a device could be made to circle the earth at higher and higher levels and escape ultimately into interplanetary space without any discomfort to passengers caused by high accelerations. The development of power for such a device must wait on a new field of research for which he proposed the name "metachemistry."

Metachemistry would concern itself with the release of energy of the

sun's radiation which impinges on the highest strata of the atmosphere and is stored in the atoms and molecules which it excites and ionizes. The energy thus stored can be used in its entirety. He said it appeared that the percentage of excited elementary particles was large and that the energy available per particle was tens to hundreds of times as great as that derived in ordinary chemical reactions.

According to Dr. Zwicky, morphological thought admits no obstacles which are man made and due to inertia, prejudice, weakness, or plain ignorance. Unless very definite reasons exist why a certain thing cannot be done, a morphologist must proceed with his analysis.

Even such a colossal problem as the reconstruction of the planetary system might not deter the morphologist. Using the power of nuclear fusion he could visualize a tremendous lopsided explosion which could be set off to bring the planets into the earth's orbit. There would be one danger though, he said. Poor or malicious handling of the operations might cause the earth to explode. But for a true morphologist, to explode the earth by mistake, would be poor form indeed, he concluded.

(The full text of Dr. Zwicky's talk will be published in the March, 1950, issue of the ARS JOURNAL.)

In closing the dinner, President Gore spoke briefly to acknowledge the assistance given him during his administration by the ARS staff. He introduced H. R. J. Grosch, incoming President of the ARS, and acknowledged with thanks the work of C. W. Chillson, who planned the 1950 Annual Convention program.

Rocket Theory

The first technical session at the 1950 Annual Convention was on rocket theory. V. N. Huff, of the National Advisory Committee for Aeronautics, Lewis Flight Propulsion Laboratory, Cleveland, Ohio, described a rapidly convergent successive approximation process which simultaneously determines both composition and temperature in a rocket combustion chamber or at the rocket exit. This method, he said, was suitable for use with any set of reactants over the complete range of mixture ratios as long as the products of reaction were assumed to be ideal gases.

A progress report on the stability of liquid films for cooling rocket motors was made by M. J. Zucrow, professor of gas turbines and jet propulsion, C. M. Beighley, and E. Knuth, all of Purdue University. In stressing the importance of film cooling, their report points out that increases in specific impulse of rocket motors introduces higher combustion temperatures and rates of heat transfer to walls of combustion chamber and exhaust nozzle.

Studies have shown that regenerative cooling becomes marginal when the combustion pressure is raised to 1200 psia. While there were many

unsolved problems relating to film cooling, the authors limit themselves to two: (1) What is the best method for introducing the coolant in a specific case? (2) What are the factors governing the stability of the liquid film after its injection into the rocket motor?

Karl Scheller and James A. Bierlein, USAF Air Materiel Command, Dayton, Ohio, in their paper, "Notes on Flow Separation in Rocket Nozzles," described an investigation of flow separation in de Laval nozzles made over a range of divergence angles and reservoir pressures using compressed air as the working fluid. What they observed indicated that the onset of separation in such nozzles was governed primarily by the reservoir pressure and the nozzle divergence angle. Some evidence was also found, they said, for the belief that scale effects played a part in the separation process. They were unable, however, to evolve a quantitative treatment to unify all the existing experimental data. This would require further experimental work, they concluded.

Long drawn-out operation of a rocket was unprofitable if aerodynamic drag would be neglected, according to H. S. Tsien and Robert C. Evans, of the Daniel and Florence Guggenheim Jet Propulsion Center, California Institute of Technology, Pasadena, Calif. In a paper on "Optimum Thrust Programming for a Sounding Rocket," they explained that for a rocket in vertical flight, the aerodynamic drag of the rocket body and the gravitational pull were in the same direction and opposite to the thrust force. It has been shown, they said, that if aerodynamic drag were absent, the best way of using the propellants was to use them in the shortest possible time. Theoretically, a rocket of given weight fraction of propellant would reach the highest altitude if the thrust were applied as a single impulse and thus the rocket would reach maximum velocity immediately, they said. This result could be understood by considering the other extreme of having the thrust equal to the weight of the rocket at every time instant. Then the rocket having zero acceleration at all times, would not be able to leave the ground.

(LEFT TO RIGHT) G. W. MADOWS, B. C. VOGEL, D. E. ALDRICH, AND H. W. DEKETT

The fifth and final paper at the Rocket Theory Session was by J. J. Ward and J. W. Clegg, of Battelle Memorial Institute, Columbus, Ohio. Their paper, "Heat Recovery and Maximum Thermodynamic Efficiency in a

Rocket," reported work to determine the maximum thermodynamic efficiency that could be obtained in a rocket by the addition of a perfect countercurrent heat exchanger. Their calculations showed that the theoretical increase was so large that the suggestion of adding a heat exchanger would appear attractive even if only a fraction of this increase was obtained in practice. Basing their calculation on a 5.0 liquid hydrogen–liquid oxygen propellant ratio, theoretical performance of a rocket with a heat exchanger showed a specific impulse increase from 349 to 462 lb sec per lb on a shifting equilibrium basis, or a 32.4 per cent increase in performance.

Rocket Operations

The session on Thursday afternoon presented three papers on the general subject of rocket operations. The discussions were touched off by Lieut. Comdr. F. C. Durant, 3d, who described the functions and facilities of the Naval Air Rocket Test Station at Lake Denmark, N. J. The station was organized to meet the need for test facilities at which government personnel could test engines of various contractors using standard methods of instrumentation. Another purpose was to provide contractors with test stands for engines of thrust greater than 10,000 lb.

The Lake Denmark site was chosen, he said, because there at the Naval Ammunition Depot, the Navy had already invested funds in rocket-test facilities now being leased to Reaction Motors, Inc. More than 650 acres were available already improved with paved roads, railroad tracks, and military housing. A bill now pending before Congress called for an appropriation of more than seven million dollars to expand and modernize facilities. As a centralized pool of rocket-engine test facilities and know-how, the station would relieve contractors of construction and maintenance of expensive test facilities of their own. The station should contribute to the reliability of future rocket engines, he stated.

The operation of expellant bags for rocket-propellant tanks was described by W. R. Sheridan, Bell Aircraft Corporation. The bag is necessary because when a rocket makes a sudden turn with its propellant tanks partially full, the motion of the missile throws the liquid to one side thus uncovering the outlet and causing an interruption of propellant supply. Mr. Sheridan commented on the care that must be given to the material of the bag, method of fabrication, and the method of installation in the tank, in order to insure satisfactory functioning of the expellant bags.

Experience gained in the operation of X-1 aircraft at the USAF Edwards Air Force Base, Muroc, Calif., pointed up the need for rocket engines of higher thrusts, long durations, and increased reliability, according to Richard F. Gompertz, whose paper, "Rocket Engine Flight Testing"[1] closed the afternoon session.

[1] Full text of Mr. Gompertz's paper appears on pages 169–176 of this issue.

(LEFT TO RIGHT) C. N. HICKMAN, E. G. UHL, M. J. ZUCROW, AND DAN A. KMIBALL

A rocket engine as the sole power plant for aircraft flight propulsion was generally ridiculed a few years ago, he said, yet since 1946 the USAF X-1 aircraft have made many successful rocket-powered flights using the same engine on successive flights. These tests have been made, however, to obtain data on the aircraft rather than on the rocket engines. The meager engine data recorded during flight have proved valuable in analysis of engine difficulties. Mr. Gompertz described preflight testing and procedure which he said was the basis for a good flight test program.

The X-1, he explained, was a research vehicle designed to obtain data at extreme altitudes and speeds. It was launched through the bomb bay of a modified B-29 or B-30. Upon reaching drop altitude, the pilot pressurized the propellant tanks and bled the liquid-oxygen lines of all trapped gases and vapors to insure that oxygen would flow in the liquid state when injected into the combustion chambers. This operation was completed 30 to 60 sec prior to drop.

In ending the flight it was considered better to shut the rocket engine before all propellants were exhausted. The remaining propellants were jettisoned, one propellant at a time to decrease danger of external ignition. The remainder of the flight was conducted as a glider and terminated in a power-off landing on the dry lake bed.

Testing and Design

The third session held on Friday morning was devoted to three papers on the general subject of testing and design.

The value of a micro-rocket of about 10 lb thrust as an experimental tool in liquid-rocket research was discussed by Bradford Darling and Saul Wolf of the Division of Industry Co-Operation, Massachusetts Institute of Technology. The advantages of safety and economy of the micro-rocket were particularly suited to the study of propellant performance, they said. A positive displacement injection system gave propellant-flow rates which were independent of variations in combustion chamber pressure.

Simplified methods of calculating theoretical performance parameters were developed which are consistent with the one per cent average in ex-

perimental data. Corrected for heat losses, micro-rocket performance was comparable to that of large-scale reaction motors of equal residence time. Results of some of their research on the effect of fuel additives and ambient conditions of temperature and pressure on starting characteristics of rocket motors, which Mr. Darling and Mr. Wolf covered in detail, substantiated their claim for the micro-rocket.

An experimental technique previously developed to determine the burning rates of solid propellants was successfully adopted for determining similar data for liquid propellants, according to C. W. Tait, A. G. Whittaker, and H. Williams of the Naval Ordnance Test Station, Inyokern, Calif. The burning rate data collected in glass tubes of 7 mm outside diameter, they reported, had a standard deviation of the mean value of 1.5 per cent.

Working with mixtures of 2-nitropropane and nitric acid, they found that the burning rate increased with the 1.1 power of pressure over the pressure range from 200 to 1000 psia and with the 4.3 power of pressure over the range 1000 to 2000 psia. In the transitional pressure region, the burning on occasion changed from the rapid to the slower mode.

Future work already planned would attempt to determine the influence of temperature of propellants on burning rate and the effect of increasing the ambient pressure above 2000 psia. Measurement of temperature through the flame and burning surface might shed light on the mechanism involved in the burnings, they said.

In the third paper C. C. Ross, chief engineer, liquid engine department, Aerojet Engineering Corporation, Azusa, Calif., in his paper on "Principles of Rocket Turbopump Design" said that an analysis of the significance of all variables that influence the design of rocket turbopumps was not always practicable. Mr. Ross presented an approach in the design of different rocket components with particular emphasis on pump parameters. The suction specific speed of the pumps, he showed, was the controlling parameter in determining the minimum fixed weight design for both auxiliary and prime rocket power plants, where such factors as pump efficiency, turbine efficiency, and propellant performance had to be individually treated depending on the specific application.

The final paper of the session was "Throttling Thrust Chamber Control," by M. Meyer, supervising rocket engineer, rocket department, Curtiss-Wright Corporation, propeller division, Caldwell, N. J.

Preprint Copies Available

Preprint copies of all papers presented at the 1950 Annual Convention may be obtained from the American Rocket Society, 29 West 39th Street, New York 18, N. Y. Price per copy is 25 cents to members; 50 cents to nonmembers.

Goddard Memorial Room

AFTER the closing session on Friday, officers of the Society and invited members attended the dedication of the Robert H. Goddard Memorial Room at the Institute of the Aeronautical Sciences, 2 East 42nd Street, New York, N. Y.

The room contains the entire library including rocket parts and mechanisms of the late Dr. Goddard, a gift to the Institute from Mrs. Esther Goddard. In the collection is the protype of the "bazooka" which was developed and was ready for production by the end of World War I in 1918. Included also are many examples of successful and unsuccessful liquid-fuel rocket motors, controls, tanks, instrumentation, firing mechanisms, fuel pumps, turbines dating from Dr. Goddard's experimentation at Worcester, Mass., Roswell, N. M., and Annapolis, Md.

Completing the exhibit are some of the latest JATO and rocket engines loaned by the United States Navy and Reaction Motors, Inc. These are typical of further developments in the field of rocketing since Dr. Goddard's death.

SOME OF THE EXHIBITS IN THE GODDARD MEMORIAL ROOM IN THE HEADQUARTERS BUILDING OF THE INSTITUTE OF THE AERONAUTICAL SCIENCES, NEW YORK, N. Y.

ARS 1950 HONORS RECIPIENTS

BIOGRAPHICAL sketches of the 1950 American Rocket Society's honors recipients follow:

Lovell Lawrence, Jr.

LOVELL LAWRENCE, JR., who received the Goddard Memorial Lecture Award of the American Rocket Society, is president of Reaction Motors, Inc., Dover, N. J.

He received his education at the Montclair State Teachers College, Montclair, N. J., and at Lehigh University, Bethlehem, Pa. He began his professional life with the Radio Type Division of the International Business Machines Corporation as assistant to the chief engineer. In this capacity he designed and supervised installation of automatic radio writing equipment for the United States Government, specializing in electrical controls.

LOVELL LAWRENCE, JR., WINNER OF THE ARS 1950 GODDARD MEMORIAL LECTURE AWARD

In 1941, Mr. Lawrence left the International Business Machines Corporation to serve as president of Reaction Motors, Inc., of which he was one of the organizers. As chairman of the board of directors and the technical and operations committee of the young company, Mr. Lawrence has played a major role in determining company policies.

Mr. Lawrence has been a member of the American Rocket Society since 1936 and is a past-president of the Society. He has also served as ARS secretary.

During World War II, he was one of the few American scientists selected to accompany the Naval Technical Mission to Europe to study German rocket development.

Col. Leslie A. Skinner

COL. LESLIE A. SKINNER, U. S. Air Force, who received the 1950 C. N. Hickman Award of the American Rocket Society, is currently assigned to Headquarters Air Armament Test Center, Eglin Air Force Base, Fla.

Colonel Skinner has had a life-long interest in rockets. The son of an army surgeon, he fired his first rocket made of bamboo and black powder when he was 16 years of age. The rocket flew fairly well but hit the hospital

COL. LESLIE A. SKINNER, WINNER OF THE ARS 1950 C. N. HICKMAN AWARD

porch and started a fire, whereupon his experiments were terminated on orders.

Colonel Skinner was born April 20, 1900, in San Francisco, Calif. After a year at Harvard University, he entered the U. S. Military Academy at West Point, N. Y., where he was graduated in 1924. Between 1924 and 1931 he was assigned to the Air Corps in various capacities such as rated airship pilot, free balloon pilot, and military airplane observer.

In 1931 he was transferred to the Ordnance Department where on his own time and expense he returned to his rocket experiments. When he was not allowed to use the lathes in the base shop after hours because of expense, Colonel Skinner went so far as to purchase his own small machine shop. In 1934 he completed the Ordnance Special Engineering Course at the Massachusetts Institute of Technology.

Colonel Skinner continued his rocket experiments. By 1938 he had fired some 1900 static and free rockets, most of which used powder propellants compounded from powder captured from German stores during World War I and from small lots furnished by the Hercules Powder Company. He was able to interest authorities sufficiently by 1936 to win official recognition, and a small sum to finance his work.

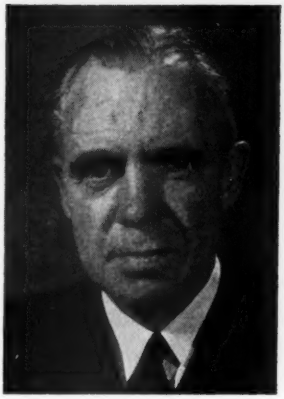
In 1940 Colonel Skinner joined Dr. C. N. Hickman in his rocket weapons work as Ordnance Department representative. Until 1943 he was chief of Ordnance Department rocket-development work and director of Army projects at Indianhead Rocket Laboratory under Dr. Hickman. He was also ordnance liaison officer with Dr. Lauritsen's Rocket Division at California Institute of Technology.

Ordered to England in June, 1943, Colonel Skinner worked for a period with Sir Alwyn Crow's staff. The following year he returned to the United States to serve as Chief of Sub-Office, Office Chief of Ordnance for Ord CIT at the California Institute of Technology.

In 1945 he was assigned to the Philippine Islands and Japan where he organized ordnance service for Service Command of the Eighth Army. Between 1946 and 1948 he was an instructor at the Army Command and General Staff College, Fort Leavenworth, Kan.

At his own request he relinquished his duties as instructor to join the Aerojet Engineering Corporation, Azusa, Calif., in February, 1948. Last year Colonel Skinner was recalled to active duty with the Air Force and served in various posts. He began his current assignment in June, 1950.

Rear Adm. Calvin M. Bolster



REAR ADM. CALVIN M. BOLSTER, FELLOW ARS

REAR ADM. CALVIN M. BOLSTER, U. S. Navy, who was elected Fellow of the American Rocket Society, is assistant chief and deputy of naval research, Navy Department, Washington, D. C. Admiral Bolster began to specialize in aeronautics early in his naval career and was among the officers who recognized the combat potentialities of rockets and jet propulsion when tactical applications of these technological developments seemed remote.

Admiral Bolster was born in Ravenna, Ohio, Aug. 17, 1897. He was graduated from the United States Naval Academy, Annapolis, Md., in 1919. These studies were continued at the Boston Navy Yard and at the Massachusetts Institute of Technology, Cambridge, Mass., where he received a degree of master of science in 1923.

Requesting duty with the Naval Aeronautical Organization, Admiral Bolster was assigned in 1923 to the Naval Air Station, Lakehurst, N. J. Here as a member of the assembly and repair department, he participated in the construction of the Navy's first dirigible, USS Shenandoah, and attended flight trials. During this period he was in charge of erection and operation of the first successful helium purification plant at Lakehurst.

Following his promotion to a lieutenant in the Construction Corps, in 1925, Admiral Bolster was assigned to the Naval Aircraft Factory, Navy Yard, Philadelphia, Pa., and to flight training at the Naval Air Station, Pensacola, Fla.

From 1927 to 1930, Admiral Bolster was experiment officer and first lieutenant on the USS Los Angeles. During this period he designed and tested the trapeze and airplane hook-up equipment which permitted airplanes to be operated from airships. First tried on the USS Los Angeles, this equipment was later installed on the airships Akron and Macon.

In 1940 Admiral Bolster was made head of the Ships and Installations Branch of the Engineering Division, Bureau of Aeronautics. Appreciating the potentialities of rocket and jet propulsion, he initiated the Navy JATO project and directed it from inception to completion. In recognition for this work, his Government awarded him the Legion of Merit medal. His insistence that naval vessels be provided with unexcelled facilities for operations and tending of aircraft was a major factor in the efficiency of fleet operations during World War II.

Following an assignment as assembly and repair officer at the Naval Air

Station, San Diego, Calif., in 1946, and as deputy and assistant chief of Naval Research, Navy Dept., Washington, D. C., in 1946, Admiral Bolster assumed his present post as assistant chief for Research and Development, Bureau of Aeronautics, in 1949. Shortly after he was promoted to Rear Admiral.

In addition to the Legion of Merit, Admiral Bolster was awarded many medals for his services during the last war, including the Honorary Command of the Military Division of the Order of the British Empire.

In 1949 he was awarded the Goddard Memorial Lecture Award of the American Rocket Society for his "vision and leadership in support of research and development throughout the field of rocket propulsion."

Louis G. Dunn

LOUIS G. DUNN, who was elected Fellow of the American Rocket Society, is director of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif.

Dr. Dunn was born in Ermelo, South Africa, Nov. 4, 1908. He obtained all of his professional education at the California Institute of Technology where he was graduated with the degree of bachelor of science in 1936. In 1937 he earned his master's degree in aeronautical engineering. He continued his studies and in 1940 received his doctor's degree in aeronautics.

Dr. Dunn's professional life has been devoted to engineering research in aeronautics and rocket technology. In 1936 he joined the Lockheed Aircraft Company, Burbank, Calif., as research engineer. The following year he returned to California Institute of Technology as research instructor. He became a research fellow in 1939 and an instructor in 1940, an assistant professor in 1941, and an associate professor in 1946.

LOUIS G. DUNN, FELLOW ARS

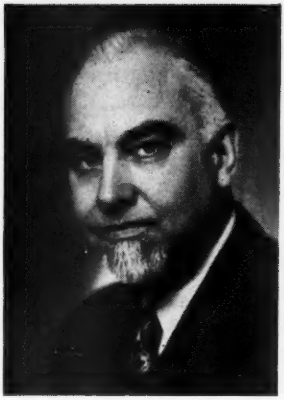
Dr. Dunn's connection with the Jet Propulsion Laboratory began in 1945 when he took the post of assistant director. The following year he was promoted to acting director and in 1947 to director of the Laboratory.

Dr. Dunn became an American citizen in 1943. He is married and has four children.

G. Edward Pendray

G. EDWARD PENDRAY, who was elected Fellow of the American Rocket

Society, is senior partner of Pendray and Company, New York, N. Y., one of the leading industrial public-relations counsels in the United States.



G. EDWARD PENDRAY, FELLOW ARS

Dr. Pendray is a writer and speaker on public relations and scientific subjects, a contributor to research particularly in the field of rockets and jet propulsion, and a leader in the advancement of economic, scientific, and engineering education. He has worked for closer co-operation between industry and education.

Dr. Pendray was born in Nebraska in 1901. He received the degree of bachelor of arts from the University of Wyoming in 1924, and the master of arts degree the following year from Columbia University. In 1943, the University of Wyoming awarded him the honorary degree of doctor of laws.

Dr. Pendray's life-long interest in education stems from his college days when he prepared himself for a teaching career. For several years he taught in the public schools of Nebraska and Wyoming.

In 1925 he joined the staff of the *New York Herald Tribune*, serving in various capacities from that of reporter to science editor. During this period he organized the first Noise Abatement Commission. In 1930 he became editorial director for the Milk Research Council, an organization sponsored by all major milk companies in the New York-New Jersey area to promote increased use of milk and milk products.

In 1936 Dr. Pendray joined the Westinghouse Electric Corporation as assistant to the president in charge of public relations. He was responsible for enlarging the scope of the corporation's public-relations program from a relatively small activity to one that encompassed the entire public-relations field on a national scale. His continuing interest in education resulted in the establishment of the Westinghouse Educational Foundation and the Westinghouse Science Talent Search which he conceived and organized.

Working to promote closer relations between industry and schools, Dr. Pendray organized the Westinghouse School Visitors System and the Westinghouse program of industry-sponsored teaching aids for schools. The program is responsible for science leaflets, handbooks, motion pictures, slides, charts, and other aids now in national use in high schools. Other agencies to which Dr. Pendray contributed are the National Science Teachers Association in 1944, and the Advisory Council on Industry-Science Teaching relations in 1947.

For the Daniel and Florence Guggenheim Foundation, he helped to

organize the Daniel and Florence Guggenheim Jet Propulsion Centers at Princeton University and the California Institute of Technology.

Dr. Pendray has been associated with the development of rocket and jet propulsion since 1930. His books, articles, and speeches on the subject did much to lift rockets out of the comic strips and into the factories of the nation. He was one of the organizers of the American Rocket Society. At various times he served the Society as editor, director, and president. With H. F. Pierce, another member, he helped to construct the first liquid-fuel rocket launched by the Society.

Mr. Pendray is a fellow of the American Association for the Advancement of Science, a member of The American Society of Mechanical Engineers, a member of the Sponsoring Committee of the National Public Relations Conferences of the National Association of Manufacturers, and many other societies.

In addition to hundreds of articles, written for the country's leading popular magazines, Dr. Pendray is author of several books among which are "The Coming Age of Rocket Power" and "Men, Mirrors, and Stars."

Maurice J. Zucrow

MAURICE J. ZUCROW, who was elected Fellow of the American Rocket Society, is professor of gas turbines and jet propulsion, Purdue University, Lafayette, Ind., where he is in charge of instruction and research in the fields of gas turbines and jet propulsion.

Dr. Zucrow was born in Russia, Dec. 15, 1899, and received his high school and university education in the United States. He was graduated magna cum laude from Harvard University, Cambridge, Mass., in 1922. The following year he took his master's degree in mechanical engineering at the same university. He received his doctor's degree from Purdue University in 1928.

M. J. ZUCROW, FELLOW ARS

Dr. Zucrow began his professional career as research associate at Purdue University in 1923, where his work was directed principally to research in internal-combustion engines. He remained at Purdue teaching thermodynamics and mechanics of fluids until 1929, when he left to become vice-president in charge of engineering of the Paragon Vaporizer Corporation, Chicago, Ill. Until 1934 Dr. Zucrow was occupied in developing carburetion equipment for burning heavy fuels in spark-ignition engines. At this time he became a partner in the consulting firm, Hubbard Engineering Company, which specialized in electric and water utilities. Between 1937

and 1940, he made public-utility valuations for several cities in Iowa and associated in the design and equipment selection for power and heating plants. In 1940, as vice-president and general manager of the Ring Balance Instrument Company, Dr. Zucrow was engaged in manufacture of industrial instruments and control devices. Thermodynamic design of gas turbines was his principal interest during 1941 and 1942, when he was research and development engineer for the Elliott Company.

In 1942 rocket technology fired Dr. Zucrow's imagination and he accepted the post of technical assistant to executive vice-president of Aerojet Engineering Corporation, Azusa, Calif. In this capacity he developed regeneratively cooled liquid-propellant rocket-propulsion equipment. He served as technical co-ordinator of engineering activities and was in charge of technical phases of solid propellant JATO production and general preliminary design. In 1946 Dr. Zucrow returned to Purdue University as professor of gas turbines and jet propulsion.

Dr. Zucrow is author of some 30 papers, articles and bulletins pertaining to carburetion, fluid dynamics, vibration, instrumentation, rockets, jet propulsion, gas turbines, and piston engines. In 1947 his book, "Principles of Jet Propulsion and Gas Turbines" was published by John Wiley and Sons, Inc. He is the holder of ten patents.

Dr. Zucrow is a member of many engineering societies including The American Society of Mechanical Engineers, several honorary fraternities, and the American Legion.

Fritz Zwicky

Fritz Zwicky, who was elected Fellow of the American Rocket Society, is research consultant and member of the advisory board, Aerojet Engineering Corporation, Azusa, Calif.

Dr. Zwicky was educated at the Federal Institute of Technology, Zurich, Switzerland. He received his bachleor of science degrees in physics and mathematics in 1922, and in the same year a doctor's degree in physics.

Upon completion of his formal education, Dr. Zwicky came to the United States and became a research fellow of the International Education Board, California Institute of Technology, Pasadena, Calif. In 1927 he took the post of assistant professor of theoretical physics and two years later was promoted to associate professor. In 1943 he was professor of astrophysics and in 1948, astronomer on the combined staff of the Mt. Wilson and Mt. Palomar Observatories.

FRITZ ZWICKY, FELLOW ARS

During the period 1941–1945, he served the Office of Civilian Defense as technical adviser. He was active in testing and constructing new means of defense against attacks with chemical warfare agents. In the summer of 1945 he was in Germany as technical representative for the Army Air Forces and later that year served in Germany and Japan as member of the Army Air Force Scientific Advisory Group. From 1946 to 1948 he was a member of the Army Air Force Scientific Advisory Board. In this capacity he was again in Europe in the fall of 1946 as a member of the Navy Technical Mission.

Dr. Zwicky served as director of research of the Aerojet Engineering Corporation from 1943 to 1949.

In addition to his professional interests, Dr. Zwicky is also active in civic activities. He is chairman of the Committee for Aid to War Stricken Scientific Libraries, and a trustee of the Pestalozzi Foundation of America. He was awarded the Medal of Freedom by President Truman in 1949.

Dr. Zwicky is a member of numerous scientific and technical societies in the United States, Switzerland, France, and England. He is author of some 150 articles in the fields of physics, chemistry, astronomy, engineering, jet propulsion, philosophy of science, education, world politics, and mountain climbing.

American Rocket Society News

ARS Indiana Section Reports Active Fall Season

IN THE wake of its successful "launching banquet" on June 8, 1950, the Indiana Section of the American Rocket Society has continued this fall with series of meetings and social events, which are stimulating interest in rocket technology among Indiana engineers.

On Oct. 11, 1950, the Section met to hear Bruce Reese talk on "Principles of Jet Propulsion." Mr. Reese is research assistant and instructor in jet propulsion at Purdue University.

Mr. Reese discussed the principles and functions of jet propulsion. The background information he provided concerning the history and principles of jet propulsion engines was helpful. He pointed out the speed limitations of the piston-propellor motor for air flight and then discussed the ram, pulse, and turbojet engines, bringing out the advantages and disadvantages of each. His lecture was concluded with a review of the development and construction of solid and liquid-fuel rockets.

Some 60 ARS members and guests met on Oct. 25, 1950, to hear a talk by Clair M. Beighley, project engineer, Navy Rocket SQUID, Purdue University. Mr. Beighley's subject was "Principles of Rocket Motors." With the aid of slides, he showed why rocket motors worked and described their components, functions, problems in construction and design, and discussed recent applications. Mr. Beighley showed color movies taken at Project SQUID. These covered construction of the laboratory, preparation for test firing, and also several test runs which had been made.

Part of the evening was devoted to a business meeting during which J. Preston Layton was elected president to fill the unexpired term of Frank T. Rynes, who left Purdue University at the end of the summer. Mr. Layton is now a graduate

student at Purdue University and is engaged in rocket research in Project SQUID. He has been working in the field of rockets and jet propulsion since receiving his BS in aeronautical engineering from New York University in 1941. After his graduation he worked with the Naval Bureau of Aeronautics on rocket research and development at Annapolis. From 1942 until 1945 he worked on the introduction of liquid and solid JATO units.

In 1946, Mr. Layton joined the Glenn L. Martin Co., where he was propulsion-group head for pilotless aircraft and project engineer on supersonic ramjet test vehicles. He was also in charge of all Viking rocket tests at White Sands.

Officers of the ARS Indiana Section met on Nov. 6 to plan winter meetings. The Section now has more than 50 active members on the Purdue campus and the number is growing rapidly.

In a discussion of the aims of the Section, M. J. Zucrow, Fellow ARS, suggested that to keep the interest of student members and rocket groups off campus, the Section should be concerned not only with rockets but also with topics related to auxiliary fields. He mentioned that the Section had responsibilities to industry and research groups in Indiana. Dr. Gilliland mentioned that the Section could perform a service by bringing together groups contributing to rocket design and construction. Plans were discussed for a semiannual banquet to be held in January, 1951.

Officers expressed pleasure over the award of the ARS Student Award for 1950 to C. M. Beighley and E. L. Knuth of the Section for their paper, "Film Cooling of Rocket Motors."

Dr. Clauser Addresses Section

At a meeting on Nov. 15, the Indiana Section extended a welcome to Milton W. Clauser, new head of the School of Aeronautical Engineering at Purdue University. Dr. Clauser spoke on "Uses of Rockets and Gas Turbines in Aircraft."

Dr. Clauser, who was associated with the Douglas Aircraft Company as chief of the mechanical-equipment section while research on the Skyrocket and the Skystreak was being conducted, explained that experimentation with the Skyrocket was for determining problems of supersonic flying and for the exploration of the transonic and supersonic regimes. In showing some of the problems encountered in the project he pointed out that since no piston propellor-type motor-driven aircraft was capable of flights at this speed, some other power unit was necessary. He demonstrated that the rocket motor with low weight but relatively high fuel consumption seemed the answer. The test aircraft was to take off and land under its own power. Because the machine was to be piloted, many safety factors had to be considered.

Regarding the question of propellants, Dr. Clauser stated that the matter of the selection of the fuel was relatively simple and that alcohol was chosen. A good easily handled oxidizer was more difficult to find, but liquid oxygen was finally selected. To pressurize the tanks, helium was used. The need of pumping action for the material was solved by the use of a turbine-driven pump (hydrogen peroxide with a catalyst).

He stressed the design and safety requirements of this aircraft over and above those of guided missiles. Particular problems, which were encountered in the designing and finding materials for valves to operate at 300 F, were mentioned.

Dr. Clauser summarized by stating that the supposedly simple problem of installing rocket motors in an airplane proved a complex, challenging, and interesting one.

ARS Publicity

AN ACCOUNT of the early days of the American Rocket Society, when G. Edward Pendray, Lovell Lawrence, Jr., and other rocket enthusiasts spent Sundays trying out crude rockets in remote fields of northern New Jersey, is given in an article on rockets in the November, 1950, issue of *Fortune*.

The article will please members of the Society for its excellent colored schematic sketch of the rocket motor manufactured by the Reaction Motors, Inc., which was used in the U. S. Navy's Viking rocket. Intended as a report for businessmen, the article reviews the history of the Reaction Motors, Inc., and the men behind it, and is optimistic about the future of the rocket industry in the United States. One of the color photographs shows Mr. Lawrence, president of Reaction Motors, Inc.; Charles W. Newhall, executive vice-president; Paul Winternitz, director of laboratories; and John Shesta, director of research and engineering, all active members of the Society.

The article relates how Mr. Pendray visited Germany in 1932 and met Willy Ley of the *Verein für Raümschiffahrt* (Society of Space Travel). Mr. Ley fascinated him with a demonstration of a small gasoline-liquid-oxygen rocket motor. On Mr. Pendray's return he inspired the ARS with such enthusiasm that within a year, members succeeded in firing one of its improved rockets 300 feet into the air. In 1938, James Wyld produced his fully regenerative rocket motor which developed a 10-lb thrust. Two weeks before Pearl Harbor, the U. S. Navy, after study of the Wyld rocket, signed a contract with the Reaction Motors, Inc., for development of a 1200-lb thrust gasoline-oxygen motor to give a jet assist to heavy flying boats on take off—the result was the famous JATO units.

While there may not be any peacetime use for rocket motors in this decade or next, the article cites the opinion attributed to Mr. Lawrence that some day "benign" use for it will be found, especially in applications calling for a prime mover of nearly limitless power and attractive efficiency.

Navy to Increase Aircraft-Rocket Production Facilities

NAVY facilities for increasing aircraft-rocket production at the Naval Ordnance Depot at Shumaker, Ark., will be expanded with the award of a $35,000,000 Navy contract to the four combined contracting firms which handled the original construction project at Shumaker during World War II. The firms are Winston Brothers Company and C. F. Haglin & Sons, Inc., Minneapolis, Minn.; Missouri Valley Constructors, Leavenworth, Kans.; and the Sollitt Construction Company, Inc., South Bend, Ind.

The new facilities will add production lines for the assembly and loading of aircraft rockets to meet the needs of the Navy, Air Force, and the Marine Corps.

The present contract also covers completion of production buildings, personnel structures, utilities, railroads, additional magazines, and grading and drainage. Work will start immediately with completion expected in a year.

Book Review

FOUNDATIONS OF AERODYNAMICS. By A. M. Kuethe and J. D. Schetzer. John Wiley & Sons, New York, N. Y.; Chapman and Hall, Ltd., London. 374 pp., 6 × 9¼ in., illustrations, charts, tables, $5.75.

REVIEWED BY JAMES R. RANDOLPH[1]

AIR is a compressible viscous fluid composed of molecules but its mathematical treatment as such is unnecessarily difficult. For practical purposes it is possible to make simplifying assumptions, provided their limitations are recognized.

Throughout this book the air is assumed to be a homogeneous fluid. This assumption is valid below an altitude of 100,000 feet, for below this limit the mean free path of the molecules is very small compared to the usual dimensions of aircraft parts.

In the first six chapters the air is also assumed to be incompressible and nonviscous. These assumptions are valid

[1] Member ARS, Lecturer in Mechanical Engineering, Pratt Institute, Brooklyn, N. Y.

for airfoil sections and structures of usual sizes up to a speed of about 200 miles per hour. Equations developed in these chapters can be used up to the speed of sound if corrections based on wind-tunnel tests are made. By resorting to swept-back wings it is possible to use these equations and wing designs based on them for planes flying at the speed of sound, but not yet subject to transonic shock phenomena.

For supersonic airfoils and structures, it becomes necessary to treat the air as compressible, and this is done in the next five chapters. But the equations are linearized by neglecting higher order terms, and the results are shown to be in satisfactory agreement with experimental data.

In chapters 12 to 16 the effects of viscosity are discussed, assuming the air to be incompressible, and this is followed by a brief introduction to the problem of viscous flow with the air recognized as compressible.

The last chapter shows how theoretical results compared with experimental results. There is an appendix on dimensional analysis, an appendix on the derivation of the Navier-Stokes and energy equations, and several tables of parameters to aid in computations. Problems are collected at the back of the book, but are labelled to show the sections to which they apply.

The text is based on lecture notes the authors have used at the University of Michigan. Chapters 1–6 and selected parts of the remainder have been taught in an undergraduate course; the rest in a one-semester course at the senior-graduate level. It may also be used for a two-semester graduate course for suitably qualified students.

The authors are respectively professor and associate professor of aeronautical engineering at the University of Michigan.

They hold advanced degrees in their subject, and have wide experience in teaching and research. Much of the material in the text has only recently been declassified.

Oak Ridge School of Reactor Technology

APPLICATIONS are now being received by the Oak Ridge School of Reactor Technology for enrollment in the 1951–1952 session, beginning Sept. 10, 1951. This school was established at the Oak Ridge National Laboratory in March, 1950, under sponsorship of the U. S. Atomic Energy Commission. Its purpose is to train engineers and scientists in the field of reactor theory and technology, in preparation for their employment in this field by the AEC or its contractors.

The Oak Ridge School of Reactor Technology will enroll students of outstanding qualifications who hold, or will receive by September, 1951, bachelor's or master's degree in chemistry, engineering, metallurgy, or physics. A limited number of recent college graduates will be accepted under category A in the status of student-employees of the Oak Ridge National Laboratory, and will be paid a monthly stipend for a twelve-month period, beginning September, 1951.

Provision is also made for trainees sponsored by government agencies and industrial organizations connected with or interested in the AEC reactor development program, category B. Applications for enrollment under this category must be made by the firms or agencies employing the applicants. Such students remain on the payrolls of their home organizations.

Much of the material presented in the curriculum of the Oak Ridge School of Reactor Technology will be classified; hence, all enrollments are contingent upon a personnel security investigation.

Further information and application forms may be obtained by writing to the Director, Oak Ridge School of Reactor Technology, Post Office Box P, Oak Ridge, Tenn. Category for which application is requested must be specified. These applications must be filed with the director of the school by March 1, 1951. Announcements of appointments will be made in April, 1951.

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